# A Method for Evaluating System Interactions in a Dynamic Work Environment

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As technology evolves, accidents may occur because human-system interactions were not considered adequately in the process. A systematic methodology can be used to evaluate the causes of mishaps and to develop recommendations that will enhance safety. A recent trend observed in underground coal mining is used to illustrate this principle because an underground mine is a dynamic work environment. Mining is characterized not only by frequent geologic changes but by technological evolution that can seriously degrade human performance and compromise worker health and safety. The case exemplified in this paper involves implementation of remotely controlled equipment for extended cut mining. Extended cut mining technology evolved with minimal ergonomic consideration even though the change from on-board to remote machine operation dramatically modified the role of the human component. In response to concern that system interactions should be examined more closely, a methodology was developed to identify hazards.

## 1. Introduction

Almost every process has a predecessor, and studying the predecessor helps to define needs and shortcomings to be addressed in the new design. It also suggests what information is needed by the users in order for them to be able to operate safely and effectively. The end users of a system can provide important feedback to better evaluate current and proposed designs. When new technology is introduced into a system, accidents may occur before it is realized that human-system interactions were not considered adequately in the design process. A systematic methodology to evaluate the causes of these mishaps and to develop remedial recommendations can enhance safety. This paper illustrates how such an approach was used to assess remote machine operation in underground coal mines.

The dynamic work environment of underground mining with its unpredictable geologic anomalies can result in numerous hazards. Most of these hazards, including mine roof collapse, occur near the working face where coal is being extracted. The face area is also where the most intricate interactions of people and equipment occur. For these reasons, a high priority has been placed upon minimizing hazards to the workers at the face. During the past decade remote control technology has been introduced to provide the safer environment. Now, machine operators are not required to be on the equipment, but can position themselves back and behind the machine. Because of that innovation, however, the technology has also provided a way for mines to take longer lengths of cuts, thus increasing production and leading to widespread adoption.

Once remote control technology began to be widely used, new issues became evident. Operator positioning was the primary human factors' concern expressed by industry personnel, but there were many technical questions involving ventilation and ground control during increased cut depths. From a researcher's perspective, the ability to answer these questions is confounded by the fact that each mine is very different in terms of geological characteristics, management and mine planning, equipment, seam height, and geographical area. Solutions are difficult to generalize. Nevertheless, it is essential to develop mechanisms for mines to evaluate new systems in order to predict and reduce accidents.

Extraction methods and equipment changes must allow for the ability of workers to adapt to changes in their dynamic mining environment. Consideration should be given to how the worker will use familiar information to make decisions in now unfamiliar situations. There will be both intended and unintended consequences. Robert Merton [1] denoted the impact these "functions" have on systems. Manifest functions are "intended and recognized by participants in the system" and latent functions are "those which are neither intended nor recognized." Merton's notion reiterates the need to provide comprehensive information for workers transitioning to a new system. Designers try to anticipate and eliminate surprises, but it is impossible to eliminate them all. How, then, will the new system affect the tasks the workers are currently used to? As suggested below, this question may be addressed and more "latent functions" predicted with a planned design process which includes strong ergonomics input to determine interactions and behaviors of participants.

## 2. Approach

A simple system or product design process involves several stages proceeding from general to specific. It starts with the definition of a need and a plan to produce a solution, and ends with a final product to monitor and evaluate. The process is iterative and each stage can be revisited at any time to improve the design of the system. It is critical to integrate ergonomics into *each* stage of the process [2]. Injuries can be reduced or avoided through proper consideration, planning, testing and retesting. Effort should be given to the human-machine-methods-environment interface from the onset. Regarding extended cut mining, the authors have investigated changes to interfaces in order to determine what impact the new process has on the worker's ability to adapt in the dynamic work environment. The following questions needed to be answered: What effect does the equipment change have on the operator and other workers in the face area? How do work methods change due to equipment change and relocation of the operator?

Several analytical methods were used to answer these questions. The methods were used interactively at different stages of the investigation.

### 2.1 *Literature Review*

An examination of the literature about new mining equipment and methods revealed that most concerns with implementation of the extended cut method lay in the areas of ground control and ventilation. These discussions centered upon regulatory compliance and production enhancements. There was little evident concern for specific operator needs. This review led to a better understanding of the system and guided development of methods that could be used to target human factors problem areas.

### 2.2 *Accident Analysis*

An important aspect of research to assess the safety of extended cut mining has been examination of accident data compiled by the Mine Safety and Health Administration (MSHA). The results of evaluations for 1990 and 1991 are provided by Bauer [3] and

Steiner [4]. Accident data of mines that had MSHA approval to take extended cuts were compared to accident data of mines which did not have extended cut approval. It was hoped that a comparison of injury incidence rates would offer insight into whether extended cut mining introduced new hazards or exacerbated existing hazards. Injury rates at mines with approval were higher than those at mines without approval, but fatality rates were lower. Mines with extended cut approval had higher injury incident rates for accidents that involved a worker being struck by or against something, accidents related to the handling of materials, and accidents involving a slip or fall. However, it was not possible to relate safety issues directly to extended cut mining activities. It would have been desirable to compare characteristics of accidents that occurred when an extended cut was being taken to those of shorter standard cuts; however, this information could not be derived from MSHA accident records. The implication to be drawn from this is that reporting methodologies should be changed to reflect changes in technology.

As a corollary, an exploratory study was initiated at two mines following the occurrence of fatal accidents to machine operators working within an intersection during extended cut mining. This study included a review of MSHA accident reports, interviews with face crew members, and meetings with representatives of MSHA, the United Mine Workers of America (UMWA), and the US Bureau of Mines (USBM). Safety concerns specific to worker activities within an intersection were identified. Although the accident data analysis had significant limitations, the results of those efforts combined with findings from the exploratory study provided insights that were used to develop more specific mine site evaluation strategies.

2.3 *Interviews*

An interview guide was developed to identify general safety issues. In particular, the goal was to determine what aspects of this technology were problematic to the mining industry. Topics included mining experience, work methods and procedures used, accidents and injuries, manual materials handling, control layout and design of equipment, visibility, ventilation, operator protection, maintenance, and general safety. Overall, workers had a positive attitude toward this technology. However, visibility of continuous miner operators and some aspects of maintenance were identified as common problems. It was learned that major differences exist in the specific type of problems encountered at each mine. A generalized solution approach would be an ineffective way to deal with diverse miner problems. Instead, data obtained from the interview guide was used to identify what areas needed further examination and to devise a systematic approach to analyze this technology.

A subsequent questionnaire was administered at mines in a particular geographical area in order to more narrowly focus some problem areas. The physical location of the operator during the turning task was an evident concern. The questionnaire also revealed a less than optimal illumination scheme on the continuous mining machine. Further research found that no changes had been made to the lighting systems on the machines since remote control was introduced.

2.4 *Activity Analysis/Structured Observations*

More information was required to determine the needs of workers doing specific tasks in the mining cycle. Work sampling techniques are frequently employed to provide information on the proportion of time spent by a worker on various activities. Ideally, collecting and analyzing information *prior* to implementing new technology would help to address potential problems. Mines that had not yet implemented extended cut technology, but were preparing to start, were identified. It was determined that useful information could be collected using work sampling techniques by examining mines both before and after implementing the longer cuts.

Operators and other mine personnel are faced with the question of where they should position themselves while remotely operating machinery. The most important factors are visibility, roof condition, ventilation and avoidance of moving machinery. The optimum location for an operator to stand may differ depending on length of cut and a number of other variables. The goal of the work sampling method was to identify differences in operator positioning in standard versus extended cuts. In particular, it was necessary to determine what cues and information were used. The locations of workers and equipment at the face area were recorded along with the direction the operators were looking and at what stage they were in the mining process. There did not appear to be a large difference between the before and after conditions. However, continuous miner operators would sometimes stand in an unsafe area in order to observe the longer cuts. Turning a crosscut appears to be the most variable and difficult task for operators regardless of length of cut. In addition to operator position and direction of view data, efforts continue to identify specific cues used to operate equipment remotely. Further research and analysis will determine the effects these changes have had on the continuous miner operator's ability to safely operate with new work methods and equipment changes.

### 2.5 *Analysis of Proposed Recommendations*

Once the human factors problem areas were more specifically defined, the next step was to investigate several alternative solutions and to study their impact on the technical aspects of the system. Work is underway to determine how to increase operator visibility through alternative mining plans and angled crosscuts. These changes rely heavily on ground control and ventilation analysis of the proposed systems. It is essential to attempt to determine the effects of these possible solutions prior to their implementation and continuously evaluate the solution after implementation.

## 3. Discussion

When changing from on-board operation to remote operation, the continuous miner operators were not the only ones impacted. Other mobile equipment operators in the face area were affected by this change as well. Before remote control, other face crew workers always knew the miner operator was on the mining machine. Now, the operator could be in several locations, presenting problems for everyone. Though work is progressing to resolve existing problems through the methods outlined, many of these concerns could already have been dealt with if a design team had integrated human factors methods in the development stages. Extended cut technology is just one example of a process that could have benefitted by early ergonomic intervention. Many industries other than mining can use this approach to evaluate current and new designs. If human factors issues are ignored, and major design decisions have been made, it is difficult to make more than minor changes after the fact. Simply put, the earlier human factors becomes involved in a design process, the better [2].

## References


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